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IUPQC Simulation for Power Quality Improvement

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Abstract--Power quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power. This paper proposes a new connection for a unified power quality conditioner (UPQC) to improve the power quality of two feeders in a distribution system. This paper illustrates how UPQC can improve the power quality by mitigating all these PQ disturbances. The proposed configuration of the UPQC is developed and verified for various Power Quality disturbances by simulating the model using MATLAB/Simulation.

Key Words-- Distribution system, power quality, UPQC, sensitive load, voltage sag, voltage-source converter (VSC), IUPQC

I. Introduction

The electric power industry comprises electricity generation (AC power), electric power transmission and ultimately electricity distribution to an electricity meter located at the premises of the end user of the electric power. The electricity then moves through the wiring system of the end user until it reaches the load. The complexity of the system to move electric energy from the point of production to the point of consumption combined with variations in weather, generation, demand and other factors provide many opportunities for the quality of supply to be compromised.

Power quality is the quality of the voltage—rather than power or electric current—that is actually described by the term “Power Quality”. Power is simply the flow of energy and the current demanded by a load which is largely uncontrollable.

To improve the quality of power for non-linear and voltage sensitive load, UPQC is one of the best solutions.[7].
Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. The shunt converter is connected in parallel to the load. It provides VAR support to the load and supply harmonic currents. Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply[2]. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor. A unified power-quality conditioner (UPQC) can perform the functions of both DSTATCOM and DVR. The UPQC consists of two voltage-source converters (VSCs) that are connected to a common dc bus. One of the VSCs is connected in series with a distribution feeder, while the other one is connected in shunt with the same feeder. The dc links of both VSCs are supplied through a common dc capacitor.
This paper presents the new connection for UPQC. i.e. Interline Unified Power Quality Conditioner (IUPQC) which is the most sophisticated mitigating device for the power quality disturbances. It was firstly introduced to mitigate the current harmonics and voltage disturbances. The main aim of the IUPQC is to hold the voltages Vt1 and Vt2 constant against voltage sag/swell/any power disturbances in either of the feeders. Many contributions were introduced to modify the configurations and the control algorithms to enhance its performance.

II. Power Quality Problems and Power Conditioner

We can define power quality problems as:
‘Any power problem that results in failure or mis-operation of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment.’
When applied to the container crane industry, the power issues which degrade power quality include:
• Power Factor
• Harmonic Distortion
• Voltage Transients
• Voltage Sags or Dips
• Voltage Swells

A power conditioner (also known as a line conditioner or power line conditioner) is a device intended to improve the quality of the power that is delivered to electrical load equipment. While there is no official definition of a power conditioner, the term most often refers to a device that acts in one or more ways to deliver a voltage of the proper level and characteristics to enable load equipment to function properly. In some usages, power conditioner refers to a voltage regulator with at least one other function to improve power quality (e.g. power factor correction, noise suppression, transient impulse protection, etc.).

The terms "power conditioning" and "power conditioner" can be misleading, as the word power" here refers to the electricity generally rather than the more technical electric power. Conditioners specifically work to smooth the sinusoidal A.C. wave form and maintain a constant voltage over varying loads.

Design of Power Conditioner

A good quality power conditioner is designed with internal filter banks to isolate the individual power outlets or receptacles on the power conditioner. This eliminates interference or "crosstalk" between components. If the application is a home theater system, the noise suppression rating listed in the technical specifications of the power conditioner will be very important. This rating is expressed in decibels (db).

The higher the db rating, the better the noise suppression. Good units start at a rating of about 40-60db for noise filtering. If a device does not state the db rating in its specs it may be better to move on to a different model or manufacturer.

The power conditioner will also have a "joule" rating. A joule is a measurement of energy or heat required to sustain one watt for one second, known as a watt second. Since electrical surges are momentary spikes, the joule rating indicates how much electrical energy the suppressor can absorb at once before becoming damaged itself. The higher the joule rating, the greater the protection.

III. Unified Power Quality Conditioner

The provision of both DSTATCOM and DVR can control the power quality of the source current and the load bus voltage. In addition, if the DVR and STATCOM are connected on the DC side, the DC bus voltage can be regulated by the shunt connected DSTATCOM while the DVR supplies the required energy to the load in case of the transient disturbances in source voltage. The configuration of such a device (termed as Unified Power Quality Conditioner (UPQC)) is shown in Fig. below. This is a versatile device similar to a UPFC. However, the control objectives of a UPQC are quite different from that of a UPFC.

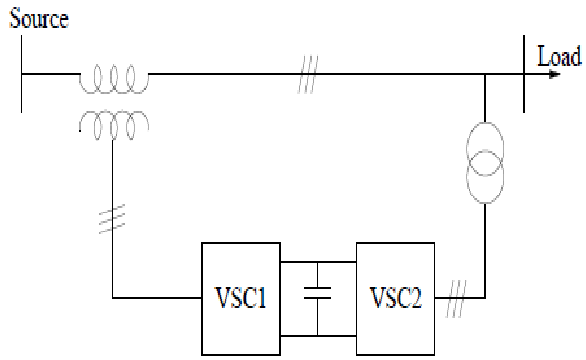

Fig. 1 UPQC control

CONTROL OBJECTIVES OF UPQC

The shunt connected converter has the following control objectives

1. To balance the source currents by injecting negative and zero sequence components required by the load
2. The compensate for the harmonics in the load current by injecting the required harmonic currents
3. To control the power factor by injecting the required reactive current (at fundamental frequency)
4. To regulate the DC bus voltage.

The series connected converter has the following control objectives:

1. To balance the voltages at the load bus by injecting negative and zero sequence voltages to compensate for those present in the source.
2. To isolate the load bus from harmonics present in the source voltages, by injecting the harmonic voltages
3. To regulate the magnitude of the load bus voltage by injecting the required active and reactive components (at fundamental frequency) depending on the power factor on the source side
4. To control the power factor at the input port of the UPQC (where the source is connected. Note that the power factor at the output port of the UPQC (connected to the load) is controlled by the shunt converter.

IV. Interline Unified Power Quality Conditioner (Iupqc)

The IUPQC shown in Fig. below consists of two VSCs (VSC-1 and VSC-2) that are connected back to back through a common energy storage dc capacitor. Let us assume that the VSC-1 is connected in shunt to Feeder-1 while the VSC-2 is connected in series with Feeder-2. Each of the two VSCs is realized by three H-bridge inverters. In its structure, each switch represents a power semiconductor device (e.g., IGBT) and an anti-parallel diode. All the inverters are supplied from a common single dc capacitor Cdc and each inverter has a transformer connected at its output.

The complete structure of a three-phase IUPQC with two such VSCs is shown in figure. The secondary (distribution) sides of the shunt-connected transformers (VSC-1) are connected in star with the neutral point being connected to the load neutral. The secondary winding of the series-connected transformers (VSC-2) are directly connected in series with the bus B-2 and load L-2. The ac filter capacitors C_f and C_k are also connected in each phase to prevent the flow of the harmonic currents generated due to switching. The six inverters of the IUPQC are controlled independently. The switching action is obtained using output feedback control. An IUPQC connected to a distribution system is shown in the figure. In this figure, the feeder impedances are denoted by the pairs (Rs1, Ls1) and (Rs2, Ls2). It can be seen that the two feeders supply the loads L-1 and L-2. The load L-1 is assumed to have two separate components—an unbalanced part (L-11) and a non-linear part (L-12). The currents drawn by these two loads are denoted by i*l*1 and i*l*2, respectively. We further assume that the load L-2 is a sensitive load that requires uninterrupted and regulated voltage.

The shunt VSC (VSC-1) is connected to bus B-1 at the end of Feeder-1, while the series VSC (VSC-2) is connected at bus B-2 at the end of Feeder-2. The voltages of buses B-1 and B-2 and across the sensitive load terminal are denoted by Vt1, V t2 , and V*l*2, respectively.

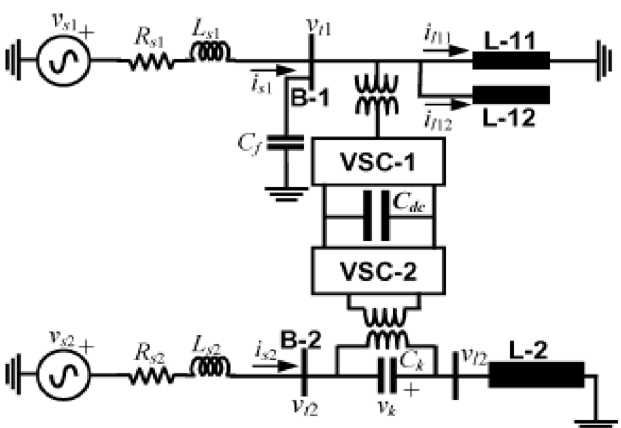

Fig. 2 IUPQC in distribution system

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V. Control Method

The method uses Sinusoidal PWM-Based Control Scheme.

In order to mitigate the simulated voltage sags in the test system of each mitigation technique, also to mitigate voltage sags in practical application, a sinusoidal PWM-based control scheme is implemented, with reference to IUPQC.

The aim of the control scheme is to maintain a constant voltage magnitude at the point where sensitive load is connected, under the system disturbance. The control system only measures the rms voltage at load point, in example, no reactive power measurements is required.

The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching (FFS) methods favored in FACTS applications. Besides, high switching frequencies can be used to improve the efficiency of the converter, without incurring significant switching losses. Fig.1 shows the IUPQC controller scheme implemented in MATLAB.

The IUPQC control system exerts voltage angle control as follows:

An error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal and generates the required angle δ to drive the error to zero, in example, the load rms voltage is brought back to the reference voltage. In the PWM generators, the sinusoidal signal, $V_{control}$, is phase modulated by means of the angle δ or delta as nominated in the Fig.1. The modulated signal, $V_{control}$ is compared against a triangular signal (carrier) in order to generate the switching signals of the VSC valves.

The main parameters of the sinusoidal PWM scheme are the amplitude modulation index, m_a , of signal $V_{control}$, and the frequency modulation index, m_f, of the triangular signal.

The amplitude index m_a is kept fixed at 1 p.u, in order to obtain the highest fundamental voltage component at the controller output. The switching frequency if is set at 450 Hz, mf = 9. It should be noted that, an assumption of balanced network and operating conditions are made.

The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively. It can be seen in Fig.1 that the control implementation is kept very simple by using only voltage measurements as feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the test results.

The PWM control scheme shown in Fig. 1 is implemented in Matlab to carry out the IUPQC test simulations. The gain of the PI controller used in this scheme is 700.

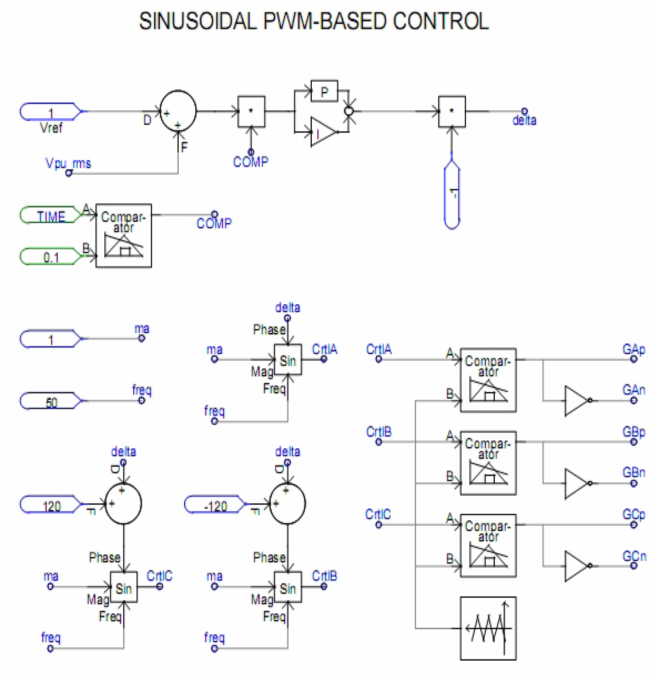

Fig. 3 PWM based control scheme

With a view to have a self regulated dc bus, the voltage across the capacitor is sensed at regular intervals and controlled by employing a suitable closed loop control. The DC link voltage, Vdc is sensed at a regular interval and is compared with its reference counterpart Vdc. The error signal is processed in a PI controller. A limit is put on the output of controller. This ensures that the source supplies active power of the load and dc bus of the UPQC. Later part of active power supplied by source is used to provide a self supported DC link of the UPQC. Thus, the DC bus voltage of the UPQC is maintained to have a proper current control. Subtraction of load currents from the reference supply currents results in three phase reference currents for the shunt inverter.

These reference currents are compared with actual shunt compensating currents and the error signals are then converted into (or processed to give) switching pulses using PWM technique which are further used to drive shunt inverter. In response to the PWM gating signals the shunt inverter supplies harmonic currents required by load. In addition to this it also supplies the reactive power demand of the load.

In effect, the shunt bi-directional converter that is connected through an inductor in parallel with the load terminals accomplishes three functions simultaneously. It injects reactive current to compensate current harmonics of the load. It provides reactive power for the load and thereby improve power factor of the system. It also draws the fundamental current to compensate the power loss of the system and make the voltage of DC capacitor constant.

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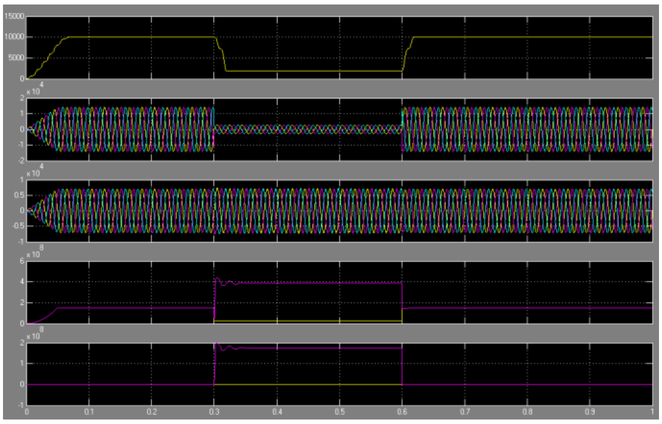
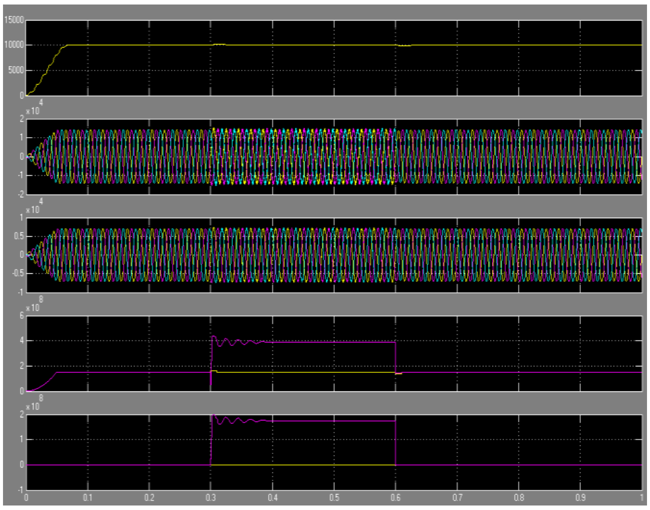
VI. SIMULATION RESULTS

A. WITHOUT UPQC

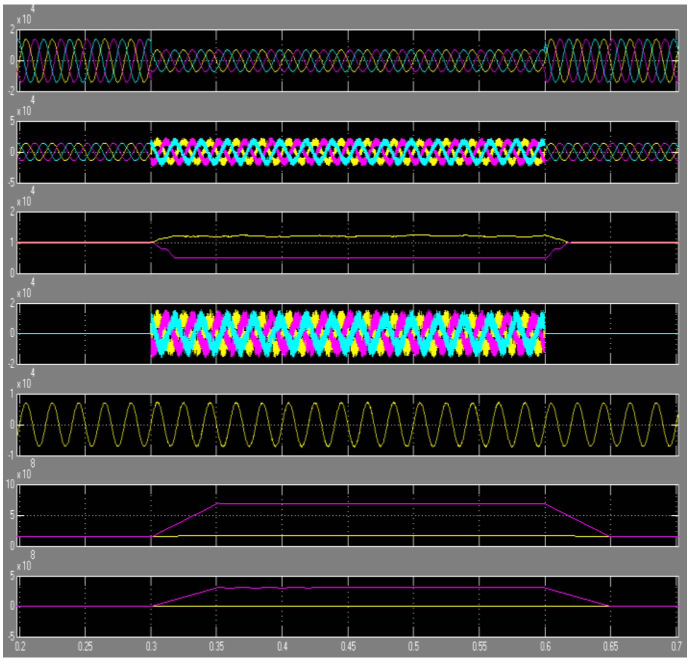


B. WITH UPQC

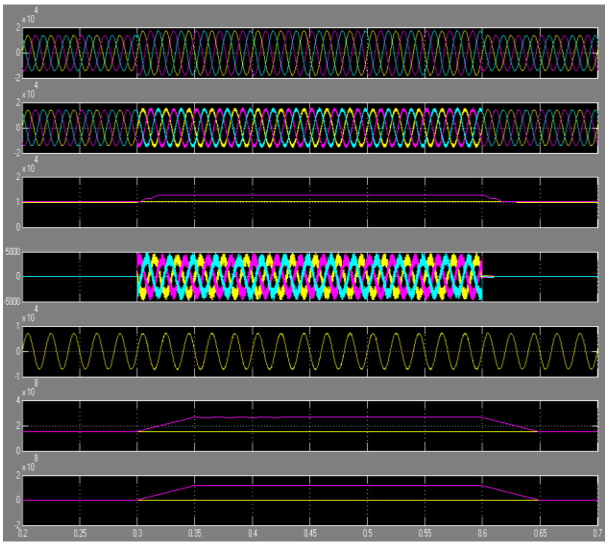


C. WITH IUPQC

1.Sag mitigation:



2.Swell mitigation:



VII. CONCLUSIONS

The performance of the IUPQC has been evaluated under various disturbance conditions such as voltage sag in either feeder, fault in one of the feeders and load change. An IUPQC is able to protect the distribution system from various disturbances occurring either in Feeder-1 or in Feeder-2. As far as the common dc link voltage is at the reasonable level, the device works satisfactorily. The angle controller ensures that the real power is drawn from Feeder-1 to hold the dc link voltage constant. Therefore, even for a voltage sag or a fault in Feeder-2, VSC-1 passes real power through the dc capacitor onto VSC-2 to regulate the voltage . Finally when a fault occurs in Feeder-2 or Feeder-2 is lost, the power required by the Load L-2 is supplied through both the VSCs. This implies that the power semiconductor switches of the VSCs must be rated such that the total power transfer through them must be possible. This may increase the cost of this device. However, the benefit that may be obtained can offset the expense.

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